Int. J. Oral Maxillofac. Surg. 2019; 48: 620–628
https://doi.org/10.1016/j.ijom.2018.11.013, available online at https://www.sciencedirect.com

International Journal of Oral & Maxillofacial Surgery

Research Paper
Orthognathic Surgery

Evaluation of the lingual fracture patterns after bilateral sagittal split osteotomy according to Hunsuck/Epker modified by an additional inferior border osteotomy using a burr or ultrasonic device

S. C. Möhlhenrich[1,2], N. Ayoub[2], F. Peters[2], P. Winterhalder[2], A. Prescher[3], F. Hölzle[2], M. Wolf[1], A. Modabber[2]
[1]Department of Orthodontics, University Hospital of RWTH Aachen, Aachen, Germany; [2]Department of Oral and Maxillofacial Surgery, University Hospital of RWTH Aachen, Aachen, Germany; [3]Institute of Molecular and Cellular Anatomy, Medical Faculty of RWTH Aachen, Aachen, Germany

S.C. Möhlhenrich, N. Ayoub, F. Peters, P. Winterhalder, A. Prescher, F. Hölzle, M. Wolf, A. Modabber: Evaluation of the lingual fracture patterns after bilateral sagittal split osteotomy according to Hunsuck/Epker modified by an additional inferior border osteotomy using a burr or ultrasonic device. Int. J. Oral Maxillofac. Surg. 2019; 48: 620–628.

Abstract. This study was conducted to compare fracture patterns and operation times after sagittal split osteotomy (SSO) by Hunsuck/Epker approach, performed using a burr or ultrasonic device, with and without osteotomy modification. A total of 80 SSOs were performed in fresh human cadavers using a burr or ultrasonic device to investigate the influence of surgical instruments as well as an additional bone cut on the inferior border of the mandible in terms of lingual fracture patterns. The times required for osteotomy and sagittal split were measured, and postoperative cone beam computed tomography images of all splits were analyzed. Without an additional inferior osteotomy, preferred splits according to Hunsuck/Epker were achieved in 35% of cases (7/20) with the burr and 45% (9/20) with the ultrasonic instrument. The inferior modification resulted in a greater number of unwanted fracture patterns in both groups. There was no relationship between the split technique and the fracture pattern ($P = 0.7854$). Statistically significant differences in osteotomy time were observed between burr osteotomy and modified burr osteotomy ($P = 0.006$), as well as modified ultrasonic osteotomy ($P < 0.001$), but not between burr and ultrasonic surgery both without the inferior cut ($P = 0.36$). The bone cut on the inferior border did not improve split control, but rather increased the risk of unwanted fractures and extended the operation time.

0901-5027/050620 + 09

Key words: bilateral sagittal split osteotomy; BSSO; fracture pattern; Hunsuck/Epker; ultrasonic surgery; Piezosurgery; osteotomy.

Accepted for publication 27 November 2018
Available online 20 December 2018

The original bilateral sagittal split osteotomy (BSSO) of the mandibular ramus was first introduced by Trauner and Obwegeser. The surgical procedure involved a horizontal osteotomy through the lingual cortex above the mandibular foramen and a second horizontal osteotomy to the buccal side. The two osteotomies were connected by a third vertical osteotomy[1]. This technique was modified by Dal Pont, who split the mandible using a vertical lateral bone cut instead of a posterior osteotomy through the body of the lower jaw[2]. Today, the Hunsuck/Epker modification for BSSO of the mandible is one of the most widely used modifications for correcting asymmetries or for mandibular advancement and setback[3]. Hunsuck recommended that the medial cortical osteotomy be extended only posteriorly to the mandibular foramen. Following this, Epker declared that removal of the pterygomasseteric sling from the ramus was unnecessary and a complete osteotomy of the inferior border of the lower jaw would minimize the risk of unwanted fractures of the distal or proximal mandible segments as well as inferior alveolar nerve injuries[4,5]. Today, the high oblique sagittal split osteotomy (HSSO) is increasingly mentioned as an alternative technique to prevent injuries to the inferior alveolar nerve[6,7].

Visual control of the fracture pattern is not possible during BSSO. However, different investigations have studied the fracture line using three-dimensional (3D) reconstructions of cone beam computed tomography (CBCT) data[8–12]. Plooij et al. reported about 51% and Song and Kim about 60% of fractures running through the mandible according to Hunsuck's description[8,10]. In addition, Möhlhenrich et al. observed that 60% of lingual surface fractures were in contact with the mandibular canal and only 23.3% of all splits ran through the lingual cortex according to the original description by Hunsuck/Epker[12].

To achieve a better split control, various studies have examined new developments in the BSSO technique as well as potential issues that could affect the split process[13–18]. In a cadaveric study, Verweij et al. modified the osteotomy design with an angled oblique buccal bone cut extended as a posteriorly aimed inferior border cut near the masseteric tuberosity and found that the modification results in a more posterior lingual fracture pattern[14]. Schoen et al. and Böckmann et al. analyzed the split behaviour of pig mandibles after a modification of the Obwegeser/Dal Pont technique by an additional osteotomy at the caudal border[17,18]. They assumed that an additional osteotomy would enable the sagittal split process through a locus of minor resistance and reported that in contrast to the classic BSSO, which led to a fracture pattern along the mandibular canal, increasing the risk of potential damage to the nerve and the risk of bad split, the BSSO with the modified osteotomy at the inferior border led to a split line closer to the inferior mandibular border and improved control of the splitting process. However, these findings were based only on a modification of the traditional Obwegeser/Dal Pont technique in pig mandibles. To date, the influence of an osteotomy of the inferior border of the mandible in the context of a BSSO according to Hunsuck/Epker has not been investigated.

Various studies have investigated the influence of ultrasonic surgery in the field of orthognathic surgery, which has become a practicable alternative to conventional instruments for orthognathic operations[19–24]. The major benefits of ultrasonic surgery devices are the minimal risk of injury to the soft tissue, vibrations without fracture if in contact with the surgical tip, outstanding overview of the operation field due to the cavitation effect and reduced bleeding, as well as high osteotomy precision due to the limited vibration amplitude and specific osteotome design, and also low acoustic and vibrational effects[25]. Furthermore, the reduction of intraoperative blood loss, lower incidence of postoperative haematoma, swelling, or nerve damage as well as earlier nerve recovery, and greater cutting precision, in the context of a longer surgical duration, have been reported[21–23,26,27]. A comparison between orthognathic surgeries performed with an ultrasonic device (Piezosurgery) and with a traditional saw revealed better results for the ultrasonic device, especially in terms of intraoperative blood loss, postoperative swelling, and nerve injury[25]. However, to date, no investigation has studied the influence of ultrasonic devices on the lingual fracture patterns in the context of BSSO.

The aim of this cadaveric study was to compare the fracture patterns after BSSO by Hunsuck/Epker approach, performed using conventional instruments (including burrs) and an ultrasonic device. This study also investigated the influence of osteotomy modification within these groups, through the use of an additional osteotomy on the inferior border of the mandible. In addition, the times required to perform surgery with the different instruments, with and without the osteotomy modification, were measured and compared.

Materials and methods

The Ethics Committee of the Medical Faculty of RWTH Aachen reviewed and approved the study design. Once institutional approval was obtained, a total of 80 SSOs were performed on 40 mandibles possessing at least the molar dentition, in fresh cadaver heads (13 female and 27 male; mean age 71 years, range 54–89 years). Either a traditional burr (Lindemann Drill; Hager & Meisinger GmbH, Neuss, Germany) (Fig. 1) or an ultrasonic device (Piezosurgery, with surgical inserts MT7-3, MT1-10, and MT2L-4 (left side) or MT2R-4 (right side); Mectron s.p.a., Carasco, Italy) (Fig. 2) was used for the SSOs, and these were done either with or without an additional osteotomy to the inferior border of the mandible. This resulted in four different groups with 20 sagittal splits per group (burr vs. ultrasonic surgery, conventional vs. modified osteotomy design), as follows: group 1, traditional burr osteotomy; group 2, modified traditional burr osteotomy; group 3, ultrasonic osteotomy; and group 4, modified ultrasonic osteotomy. The same surgeon performed all operations.

An incision was made using a knife (No. 15 blade) in the depth of the vestibule adjacent to the region of the second molar. The incision extended both anteriorly and posteriorly for a total length of about 4 cm. The incision was carried down to the bone. Sub-periosteal dissection exposed the anterior aspect of the lateral ramus and the posterior body of the mandible down to the inferior border. The extent of the dissection anterior to the gonial angle depended on the planned buccal extension of the proximal segment. The dissection exposed the anterior superior aspect of the

Fig. 1. Left side of the ramus osteotomized using traditional burr instruments before splitting.

ramus up towards the coronoid process, with stripping of the temporalis muscle tendon. Retraction of the soft tissues was performed using a ramus retractor on the coronoid process, involving a channel retractor superior to the neurovascular bundle and an inferior border retractor placed anterior to the gonial angle.

The lingual osteotomy was performed according to Hunsuck, as mentioned above, and just posterior to the mandibular foramen through the cortical bone. The buccal osteotomy through the cortical bone was performed in the region between the first and second molar. Both osteotomies were combined by a third osteotomy along the oblique line (Figs. 1 and 2). In groups 2 and 4, an additional fourth osteotomy of about 10 mm was performed on the inferior border of the mandible (Fig. 3a,b). The inferior border cut was intended to penetrate through the caudal cortex completely. However, in group 2, this osteotomy was performed using a burr under continuous spreading of the distal and proximal segments, and in group 4, left- or right-angled surgical inserts were used. However, in the case of a recognizable unwanted fracture, a complete split of the mandibular ramus was performed.

For analysis of the fracture patterns, the lingual split scale (LSS) introduced by Plooij et al. (Fig. 4)[8] was used. LSS1 is described as a vertical fracture pattern to the inferior border of the mandible, LSS2 is classified as a horizontal fracture pattern to the border of the posterior ramus, LSS3 is classified as a fracture pattern through the mandibular canal to the inferior border of the mandible, and LSS4 describes other unwanted fracture patterns, such as buccal plate fracture or a bad split.

For all cadaver heads, postoperative control CBCT scans (GALILEOS CBCT; Sirona, Bensheim, Germany) were performed to analyze the lingual cortical plates using the 3D reconstructions of the CBCT dataset with the secondary reconstruction image aligned on the fracture line (Fig. 5a–d). In addition, the times required for the osteotomy and for the mandible split were measured.

Statistical analysis

The statistical analysis of the fracture patterns according to the split technique as well as the surgical device was performed using the statistical program GraphPad Prism version 7 (GraphPad Software Inc., La Jolla, CA, USA). The relationship between the fracture pattern and the split technique or the surgical device was analyzed using the χ^2 test;

Fig. 2. Left side of the ramus osteotomized using ultrasonic surgical instruments before splitting.

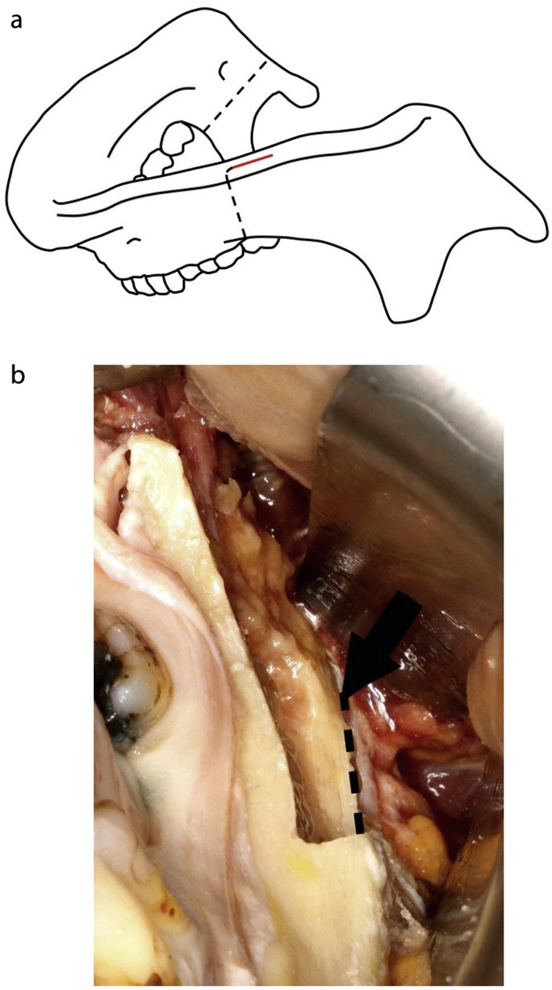

Fig. 3. (a) Schematic illustration of the mandible with the osteotomy lines, lingual and lateral, shown as black dotted lines; the red line indicates the additional osteotomy at the inferior border used in the modified technique. (b) Clinical situation after the mandible split using the modified technique with the inferior border osteotomy (arrow: black dotted line).

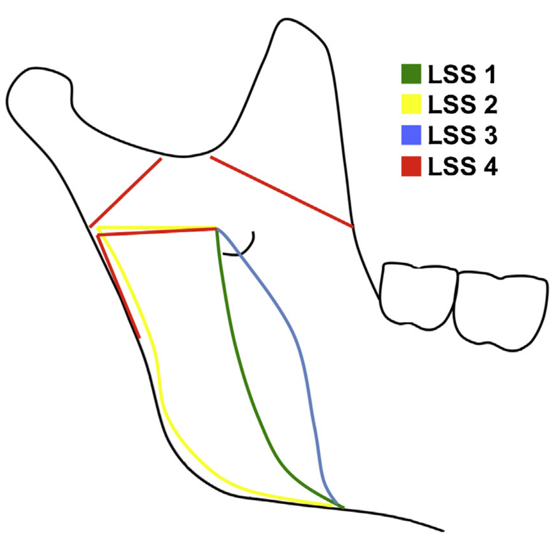

Fig. 4. Classification of the BSSO split patterns according to Plooij et al.[8]. LSS1 (green): vertical fracture pattern to the inferior border of the mandible; LSS2 (yellow): horizontal fracture pattern to the posterior border of the ramus; LSS3 (blue): fracture pattern through the mandibular canal to the inferior border of the mandible; and LSS4 (red): other unwanted patterns, such as buccal plate fracture or bad split.

in cases of small numbers of expected observed frequency for particular outcomes, Fisher's exact test was used. One-way analysis of variance (ANOVA) for multiple comparisons was used to compare the osteotomy times and the split times. The level of significance was set at $P \leq 0.05$ for all analyses and all data are expressed as the mean $\pm$ standard deviation.

Results

The distribution of the four different fracture patterns according to the osteotomy technique and the surgical device is depicted in Fig. 6. Table 1 shows the percentage distribution of the fracture patterns for all the four techniques according to the classification of Plooij et al. The comparisons between the time measurements for osteotomy and the mandible split are shown in box plot charts in Fig. 7.

The modification of the BSSO using an additional fourth osteotomy resulted in a greater number of unwanted fracture patterns, as described by Plooij et al. In the burr group, there were six unwanted fractures with the use of the modification and only two fractures without the modification. A similar distribution was observed in the ultrasonic group, four with the additional osteotomy and two without the osteotomy. Conversely, a larger number of the intended lingual split lines was found in the burr group as well as in the ultrasonic group if the additional fourth osteotomy was omitted. In all four groups, a similar distribution was observed for classifications LSS2 and LSS3. Within the study groups, the intended fracture patterns that most often occurred were LSS1 and LSS3 (which runs through the mandibular canal to the inferior mandibular border), except in the modified burr group. In this group, LSS3 occurred most frequently, followed by unwanted fractures of LSS4. However, there was no relationship between the split technique and the fracture pattern ($P = 0.7854$).

Regarding the time required for osteotomy, statistically significant differences were observed between traditional burr osteotomy and modified burr osteotomy ($P = 0.006$), as well as modified ultrasonic osteotomy ($P < 0.001$) (Fig. 7a). The split time was obviously shorter by traditional osteotomy without modification. However, there was no statistically significant difference when compared with the ultrasonic osteotomy ($P = 0.36$). The additional osteotomy resulted in a statistically significant prolongation of the operating time in both groups (burr

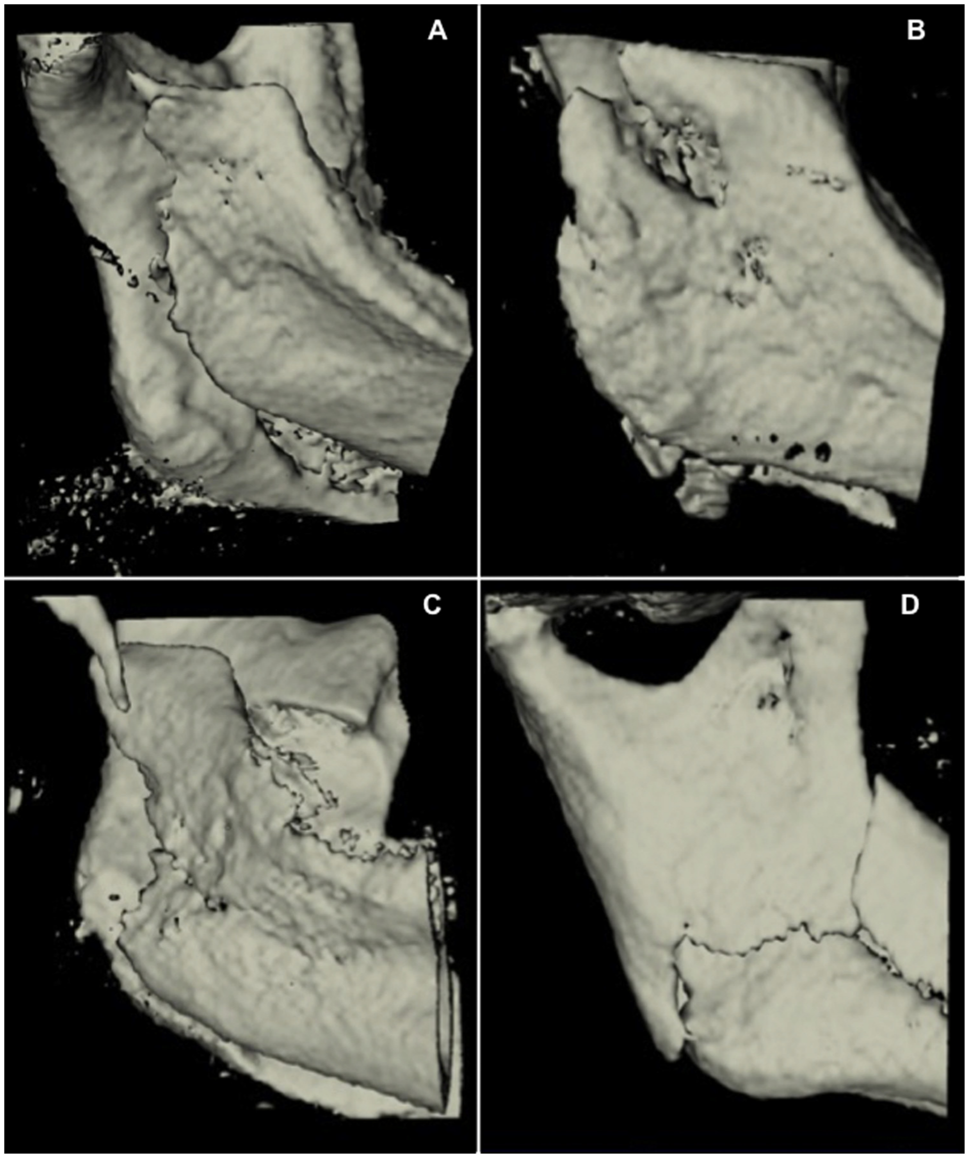

Fig. 5. Split patterns according to the classification of Plooij et al.[8]. in the three-dimensional dataset and the fracture line aligned secondary reformation: (a) LSS1, (b) LSS2, (c) LSS3, and (d) LSS4.

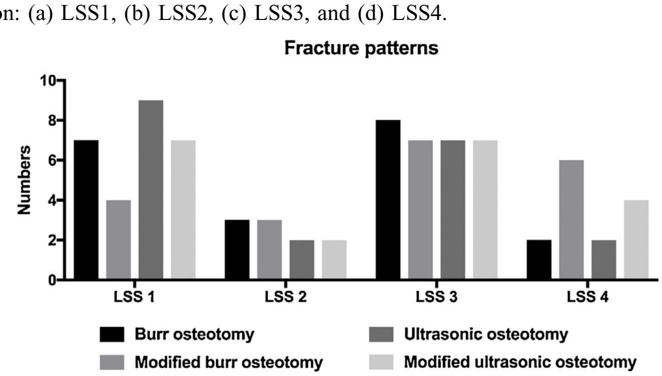

Fig. 6. Distribution of the four different fracture patterns depending on the osteotomy technique and the surgical device.

osteotomy: $P = 0.006$; ultrasonic osteotomy: $P < 0.001$).

Regarding the subsequent time to split the mandible, a statistically significant difference was observed only between the two modified variants ($P = 0.003$) (Fig. 7b). No significant difference in split time was found after the additional osteotomy was performed at the lower border of the mandible for either the burr osteotomy group ($P = 0.09$) or the ultrasonic osteotomy group ($P = 0.15$).

Discussion

An established method for the evaluation of the lingual fracture patterns after BSSO involves 3D investigation using CBCT and 3D reconstruction software[8–12]. After BSSO according to the Hunsuck/Epker method, Plooij et al. found that 32.5% of all fractures occurred along the lingual surface with contact to the mandibular canal, 13.75% of the fractures ran horizontally with contact to the border of the posterior ramus, and 2.5% were buccal or other kinds of fracture patterns[8]. Only

Table 1. Distribution of fracture pattern for all four techniques according to the classification of Plooij et al.[8]

Fracture pattern	All split techniques		Burr osteotomy			Modified burr osteotomy			Ultrasonic osteotomy			Modified Ultrasonic osteotomy		
	(n)	(%)	(n)	(%[a])	(%[b])	(n)	(%[a])	(%[b])	(n)	(%[a])	(%[b])	(n)	(%[a])	(%[b])
LSS 1	27	33.75	7	25.9	35	4	14.8	20	9	33.3	45	7	25.9	35
LSS 2	10	12.5	3	30	15	3	30	15	2	20	10	2	20	10
LSS 3	29	36.25	8	27.6	40	7	24.1	35	7	24.1	35	7	24.1	35
LSS 4	14	17.5	2	14.3	10	6	42.9	30	2	14.3	10	4	28.6	20

[a] Percentage based on particular fracture pattern.
[b] Percentage based on osteotomy technique.

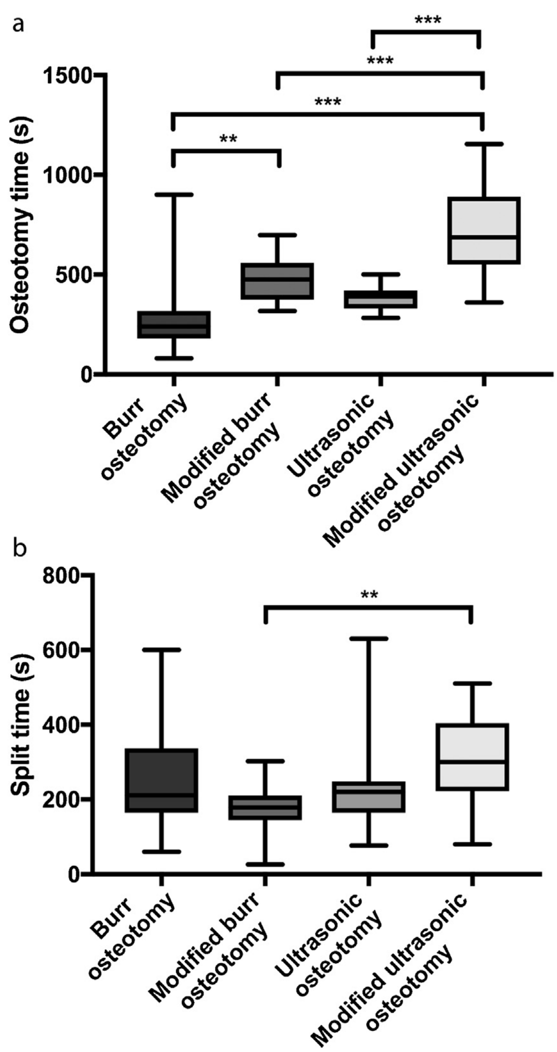

Fig. 7. Comparisons between the time measurements in seconds for (a) osteotomy and (b) mandible split; $*P \leq 0.05$, $**P \leq 0.01$, $***P \leq 0.001$.

51.75% of the fracture patterns were in accordance with the Hunsuck/Epker description. Muto et al. reported that nearly 63% of splits of the mandibular ramus ran through the lingual cortex, 23% in the posterior border of the mandible, and 15% in the buccal cortex[9]. Song and Kim determined that after Hunsuck/Epker osteotomy technique, 60% of the fracture patterns were vertical to the inferior border of the mandible, 11.25% ran through the mandibular canal to the inferior border, 21.25% showed an oblique pattern to the posterior border, and only 7.5% led to bad or unwanted splits[10]. Recently, the present study group reported that only 23.3% of all splits after Hunsuck/Epker modification led to the desired fracture pattern, whereas 6.7% resulted in horizontal fracture lines and 60% of the fractures ran through the mandibular canal[12]. Furthermore, 10% of the fractures demonstrated other fracture patterns, i.e., buccal plate fracture or bad splits.

Regarding the small number of intended lingual fracture lines and simultaneously the high incidence of bad splits and unwanted fracture patterns, various ex vivo and in vitro studies have aimed at improving the surgical procedure of SSO. These modifications include, among others, the use of special surgical instruments such as splitters and separators, anatomical features such as the mandibular canal and the mylohyoid groove, and modifications of the split technique such as using an angled lateral osteotomy or an additional osteotomy at the caudal rim of the mandible[14–18,28].

Schoen et al. and Böckmann et al. investigated ex vivo the split behaviour of pig mandibles after a modification of the Obwegeser/Dal Pont technique with an additional osteotomy at the caudal border[17,18]. It was anticipated that the additional fourth osteotomy would enable the sagittal split process due to a locus of minor resistance. They reported that the split modification led to a fracture line closer to the inferior border of the mandible and improved control of the splitting process compared with the Obwegeser/Dal Pont technique, which resulted in a fracture line along the mandibular canal, exposing the nerve to potential injury and increasing the risk of a bad split. Nevertheless, the use of animal models remains controversial. Mensink et al. also analyzed the fracture behaviour in pig mandibles using splitters and separators[16]. In this context, they reported that regardless of the instrument, the fracture pattern in the pig's jaw almost ended in the mandibular foramen, and they attributed this to animal-specific bony resistance.

In the present study, dentulous mandibles in fresh cadaver heads were used and the surgical treatments were conducted directly to provide a situation closer to clinical reality. In general, operations in this field of research have been performed after surgical resection and with soft tissue reflected mandibles, followed by rigid fixation in a test rig.

In contrast to the investigations by Schoen et al. and Böckmann et al., no advantages in terms of lingual fracture behaviour after a previous osteotomy at the lower margin of the mandible were found in this study. The preferred split according to Hunsuck/Epker was achieved in 35% of cases (7/20) with the burr and 45% (9/20) with the ultrasonic instruments without the osteotomy modification; with the additional fourth osteotomy, the preferred split was achieved in 20% of the cases with the burr (4/20) and 35% of the cases with the ultrasonic device (7/20). In contrast, the inferior border cut appears to favour a higher incidence of bad splits and unwanted fracture patterns. Thus, in the burr as well as the ultrasonic osteotomy group, 10% (2/20) of the fractures ended up with bad splits or unwanted fracture patterns, followed by the modified ultrasonic group with 20% (4/20) and then the modified burr osteotomy with 30% (6/20). In total, 36.25% (29/80) of all splits resulted in contact with the mandibular canal. The higher incidence of unwanted fracture patterns could be explained by the fact that performing bone cuts under continuous spreading is more risky. However, no correlation was found between the split technique and the lingual fracture line. In particular, no differences were recognized between the traditional burr and the ultrasonic osteotomy. Therefore, surgical instrumentation appears to play a minor role in this context. However, it must be mentioned that in addition to the surgical instruments used in this study, there are also saw blades that could be quicker and more precise, especially compared to burr devices.

Ultrasonic surgery has become an increasingly established system of bone cutting to prevent soft tissue injuries. It is indicated for surgical procedures such as bone graft harvesting, tooth extraction, maxillary sinus lifting, osteogenic distraction, and orthognathic surgery[29]. Various studies have reported reduced postoperative complications such as oedema, bleeding, and lesions to the inferior alveolar nerve after using piezoelectric surgery for SSO of the mandibular ramus[21,25,30]. However, the prolonged time needed to perform the bone cuts and the necessity of completing the osteotomies using different surgical inserts are the major limitations of using ultrasonic devices in orthognathic surgery[31–33].

In a recent systematic review, Silva et al. compared piezoelectric surgery and a conventional saw for SSO sand reported that it took longer to perform the osteotomies using the ultrasonic device than using the conventional saw[34]. However, they found no uniformity regarding the measurement of the operating time. Among the five studies that evaluated the duration of surgery[21,25,30,35,36], three assessed the time required to perform a bilateral SSO along with a Le Fort I osteotomy[21,30,36] and two studies assessed the operating time required to perform a one-sided SSO[25,35]. In this context, the time required can be influenced by differences in osteotomy design to prepare the mandibular ramus for the sagittal split. Thus, extended or additional bone cuts may prolong the surgical time, regardless of the surgical instruments. In contrast, the results of this investigation suggested that there was no significant difference in time taken between the use of the burr and the ultrasonic device. However, the modification led to a significant extension of the operating time in both groups, particularly for the ultrasonic surgery group. The shortest split time was observed during conventional burr surgery, and the longest split time was observed during modified ultrasonic surgery. Furthermore, the modification of the osteotomy technique appeared to have no influence on the sagittal split time. A significant difference was observed only between the two modified operation procedures.

In conclusion, in contrast to the current literature, there were no differences in operation time between traditional burr and ultrasonic surgery when performing the SSO according to Hunsuck/Epker. Only the split modification with a fourth osteotomy at the inferior border of the mandible resulted in significant differences in surgical duration, especially in the ultrasonic surgery group. However, the additional bone cut did not lead to better control of the lingual fracture pattern. On the contrary, this resulted in more unwanted and less desired fracture lines. However, clinical investigations must be performed to prove this. Thus, within the limitations of the cadaveric study design, ultrasonic surgery is equivalent to traditional instruments in terms of the time required for the sagittal split. Therefore, surgical instrumentation appears to play a minor role while performing SSO. An additional osteotomy at the inferior margin of the mandible can be dispensed with, because it appears to prolong the operating time unnecessarily and simultaneously increase the risk for the development of bad splits.

Funding

This study was provided grant funding by ‘‘DFG — Deutsche Forschungsgemeinschaft (grant number MO 3275/1-1). The ultrasonic instruments were provided free of charge by Mectron Medical.

Competing interests

The authors do not have any financial interests or commercial associations to disclose.

Ethical approval

Only institutional approval was necessary, however ethical approval was also given by the Ethics Committee of the Medical Faculty of RWTH Aachen (EK 219/16).

Patient consent

Not required.

References

1. Trauner R, Obwegeser H. The surgical correction of mandibular prognathism and retrognathia with consideration of genioplasty. I. Surgical procedures to correct mandibular prognathism and reshaping of the chin. *Oral Surg Oral Med Oral Pathol* 1957;**10**:677–89. contd.
2. Dal Pont G. Retromolar osteotomy for the correction of prognathism. *J Oral Surg Anesth Hosp Dent Serv* 1961;**19**:42–7.
3. Thiele OC, Kreppel M, Bittermann G, Bonitz L, Desmedt M, Dittes C, Dorre A, Dunsche A, Eckert AW, Ehrenfeld M, Fleiner B, Frerich B, Gaggl A, Gerressen M, Gmelin L, Hammacher A, Hassfeld S, Heiland M, Hemprich A, Hidding J, Holzle F, Howaldt HP, Iizuka T, Kater W, Klein C, Klein M, Kohnke RH, Kolk A, Kubler AC, Kubler NR, Kunkel M, Kuttenberger JJ, Kreusch T, Landes C, Lehner B, Mischkowski RA, Mokros S, Neff A, Nkenke E, Palm F, Paulus GW, Piesold JU, Rasse M, Rodemer H, Rothamel D, Rustemeyer J, Sader R, Scheer M, Scheffler B, Schippers C, Schliephake H, Schmelzeisen R, Schramm A, Spitzer WJ, Stoll C, Terheyden H, Weingart D, Wiltfang J, Wolff KD, Ziegler CM, Zoller JE. Moving the mandible in orthognathic surgery—a multicenter analysis. *J Craniomaxillofac Surg* 2016;**44**:579–83. http://dx.doi.org/10.1016/j.jcms.2016.01.024.

4. Hunsuck EE. A modified intraoral sagittal splitting technic for correction of mandibular prognathism. *J Oral Surg* 1968;**26**:250–3.
5. Epker BN. Modifications in the sagittal osteotomy of the mandible. *J Oral Surg* 1977;**35**:157–9.
6. Seeberger R, Asi Y, Thiele OC, Hoffmann J, Stucke K, Engel M. Neurosensory alterations and function of the temporomandibular joint after high oblique sagittal split osteotomy: an alternative technique in orthognathic surgery. *Br J Oral Maxillofac Surg* 2013;**51**:536–40. http://dx.doi.org/10.1016/j.bjoms.2012.11.016.
7. Möhlhenrich SC, Kamal M, Peters F, Fritz U, Hölzle F, Modabber A. Bony contact area and displacement of the temporomandibular joint after high-oblique and bilateral sagittal split osteotomy: a computer-simulated comparison. *Br J Oral Maxillofac Surg* 2016;**54**:306–11. http://dx.doi.org/10.1016/j.bjoms.2015.12.020.
8. Plooij JM, Naphausen MT, Maal TJ, Xi T, Rangel FA, Swennen G, de Koning M, Borstlap WA, Berge SJ. 3D evaluation of the lingual fracture line after a bilateral sagittal split osteotomy of the mandible. *Int J Oral Maxillofac Surg* 2009;**38**:1244–9. http://dx.doi.org/10.1016/j.ijom.2009.07.013.
9. Muto T, Takahashi M, Akizuki K. Evaluation of the mandibular ramus fracture line after sagittal split ramus osteotomy using 3-dimensional computed tomography. *J Oral Maxillofac Surg* 2012;**70**:e648–52. http://dx.doi.org/10.1016/j.joms.2012.07.048.
10. Song JM, Kim YD. Three-dimensional evaluation of lingual split line after bilateral sagittal split osteotomy in asymmetric prognathism. *J Korean Assoc Oral Maxillofac Surg* 2014;**40**:11–6. http://dx.doi.org/10.5125/jkaoms.2014.40.1.11.
11. Dreiseidler T, Bergmann J, Zirk M, Rothamel D, Zoller JE, Kreppel M. Three-dimensional fracture pattern analysis of the Obwegeser and Dal Pont bilateral sagittal split osteotomy. *Int J Oral Maxillofac Surg* 2016;**45**:1452–8. http://dx.doi.org/10.1016/j.ijom.2016.06.012.
12. Möhlhenrich SC, Kniha K, Peters F, Ayoub N, Goloborodko E, Hölzle F, Fritz U, Modabber A. Fracture patterns after bilateral sagittal split osteotomy of the mandibular ramus according to the Obwegeser/Dal Pont and Hunsuck/Epker modifications. *J Craniomaxillofac Surg* 2017;**45**:762–7. http://dx.doi.org/10.1016/j.jcms.2017.02.012.
13. Verweij JP, Mensink G, Houppermans PN, Frank MD, van Merkesteyn JP. Investigation of the influence of mallet and chisel techniques on the lingual fracture line and comparison with the use of splitter and separators during sagittal split osteotomy in cadaveric pig mandibles. *J Craniomaxillofac Surg* 2015;**43**:336–41. http://dx.doi.org/10.1016/j.jcms.2015.01.001.
14. Verweij JP, Mensink G, Houppermans PN, van Merkesteyn JP. Angled osteotomy design aimed to influence the lingual fracture line in bilateral sagittal split osteotomy: a human cadaveric study. *J Oral Maxillofac Surg* 2015;**73**:1983–93. http://dx.doi.org/10.1016/j.joms.2015.02.030.
15. Mensink G, Gooris PJ, Bergsma EJ, Frank MH, van Gemert JT, van Merkesteyn JP. Is the lingual fracture line influenced by the mandibular canal or the mylohyoid groove during a bilateral sagittal split osteotomy? A human cadaveric study. *J Oral Maxillofac Surg* 2014;**72**:973–9. http://dx.doi.org/10.1016/j.joms.2013.09.043.
16. Mensink G, Gooris PJ, Bergsma JE, Wes JT, van Merkesteyn JP. Bilateral sagittal split osteotomy in cadaveric pig mandibles: evaluation of the lingual fracture line based on the use of splitters and separators. *Oral Surg Oral Med Oral Pathol Oral Radiol* 2013;**116**:281–6. http://dx.doi.org/10.1016/j.oooo.2013.03.019.
17. Schoen P, Frotscher M, Eggeler G, Kessler P, Wolff KD, Boeckmann R. Modification of the bilateral sagittal split osteotomy (BSSO) in a study using pig mandibles. *Int J Oral Maxillofac Surg* 2011;**40**:516–20. http://dx.doi.org/10.1016/j.ijom.2010.09.028.
18. Böckmann R, Schon P, Frotscher M, Eggeler G, Lethaus B, Wolff KD. Pilot study of modification of the bilateral sagittal split osteotomy (BSSO) in pig mandibles. *J Craniomaxillofac Surg* 2011;**39**:169–72. http://dx.doi.org/10.1016/j.jcms.2010.04.002.
19. Stubinger S, Kuttenberger J, Filippi A, Sader R, Zeilhofer HF. Intraoral Piezosurgery: preliminary results of a new technique. *J Oral Maxillofac Surg* 2005;**63**:1283–7. http://dx.doi.org/10.1016/j.joms.2005.05.304.
20. Kotrikova B, Wirtz R, Krempien R, Blank J, Eggers G, Samiotis A, Muhling J. Piezosurgery—a new safe technique in cranial osteoplasty? *Int J Oral Maxillofac Surg* 2006;**35**:461–5. http://dx.doi.org/10.1016/j.ijom.2005.12.006.
21. Landes CA, Stubinger S, Ballon A, Sader R. Piezoosteotomy in orthognathic surgery versus conventional saw and chisel osteotomy. *Oral Maxillofac Surg* 2008;**12**:139–47. http://dx.doi.org/10.1007/s10006-008-0123-7.
22. Landes CA, Stubinger S, Rieger J, Williger B, Ha TK, Sader R. Critical evaluation of piezoelectric osteotomy in orthognathic surgery: operative technique, blood loss, time requirement, nerve and vessel integrity. *J Oral Maxillofac Surg* 2008;**66**:657–74. http://dx.doi.org/10.1016/j.joms.2007.06.633.
23. Gilles R, Couvreur T, Dammous S. Ultrasonic orthognathic surgery: enhancements to established osteotomies. *Int J Oral Maxillofac Surg* 2013;**42**:981–7. http://dx.doi.org/10.1016/j.ijom.2012.12.004.
24. Möhlhenrich SC, Ayoub N, Fritz U, Prescher A, Hölzle F, Modabber A. Evaluation of ultrasonic and conventional surgical techniques for genioplasty combined with two different osteosynthesis plates: a cadaveric study. *Clin Oral Investig* 2017;**21**:2437–44. http://dx.doi.org/10.1007/s00784-016-2040-8.
25. Spinelli G, Lazzeri D, Conti M, Agostini T, Mannelli G. Comparison of Piezosurgery and traditional saw in bimaxillary orthognathic surgery. *J Craniomaxillofac Surg* 2014;**42**:1211–20. http://dx.doi.org/10.1016/j.jcms.2014.02.011.
26. Eggers G, Klein J, Blank J, Hassfeld S. Piezosurgery: an ultrasound device for cutting bone and its use and limitations in maxillofacial surgery. *Br J Oral Maxillofac Surg* 2004;**42**:451–3. http://dx.doi.org/10.1016/j.bjoms.2004.04.006.
27. Gonzalez-Garcia R. Endoscopically-assisted subcondylar and vertical ramus osteotomies for the treatment of symmetrical mandibular prognathism. *J Craniomaxillofac Surg* 2012;**40**:393–5. http://dx.doi.org/10.1016/j.jcms.2011.07.003.
28. Mensink G, Gooris PJ, Bergsma JE, van Hooft E, van Merkesteyn JP. Influence of BSSO surgical technique on postoperative inferior alveolar nerve hypoesthesia: a systematic review of the literature. *J Craniomaxillofac Surg* 2014;**42**:976–82. http://dx.doi.org/10.1016/j.jcms.2014.01.019.
29. Pavlikova G, Foltan R, Horka M, Hanzelka T, Borunska H, Sedy J. Piezosurgery in oral and maxillofacial surgery. *Int J Oral Maxillofac Surg* 2011;**40**:451–7. http://dx.doi.org/10.1016/j.ijom.2010.11.013.
30. Landes C, Tran A, Ballon A, Santo G, Schubel F, Sader R. Low to high oblique ramus piezoosteotomy: a pilot study. *J Craniomaxillofac Surg* 2014;**42**:901–9. http://dx.doi.org/10.1016/j.jcms.2014.01.008.
31. Bertossi D, Lucchese A, Albanese M, Turra M, Faccioni F, Nocini P, Rodriguez YBR. Piezosurgery versus conventional osteotomy in orthognathic surgery: a paradigm shift in treatment. *J Craniofac Surg* 2013;**24**:1763–6. http://dx.doi.org/10.1097/SCS.0b013e31828f1aa8.
32. Khambay BS, Walmsley AD. Investigations into the use of an ultrasonic chisel to cut bone. Part 2: cutting ability. *J Dent* 2000;**28**:39–44.
33. Khambay BS, Walmsley AD. Investigations into the use of an ultrasonic chisel to cut bone. Part 1: forces applied by clinicians. *J Dent* 2000;**28**:31–7.
34. Silva LF, Carvalho-Reis ENR, Bonardi JP, de Lima VN, Momesso GAC, Garcia-Junior IR, Faverani LP. Comparison between piezoelectric surgery and conventional saw in sagittal split osteotomies: a systematic review. *Int J Oral Maxillofac Surg* 2017;**46**:1000–6. http://dx.doi.org/10.1016/j.ijom.2017.03.024.
35. Beziat JL, Bera JC, Lavandier B, Gleizal A. Ultrasonic osteotomy as a new technique in craniomaxillofacial surgery. *Int J Oral Maxillofac Surg* 2007;**36**:493–500. http://dx.doi.org/10.1016/j.ijom.2007.01.012.
36. Bruckmoser E, Bulla M, Alacamlioglu Y, Steiner I, Watzke IM. Factors influencing

neurosensory disturbance after bilateral sagittal split osteotomy: retrospective analysis after 6 and 12 months. *Oral Surg Oral Med Oral Pathol Oral Radiol* 2013;**115**:473–82. http://dx.doi.org/10.1016/j.oooo.2012.08.454.

Address:
Stephan Christian Möhlhenrich
Department of Orthodontics
RWTH Aachen University Hospital
Pauwelsstraße 30
52074 Aachen
Germany
Tel.: +49 241 8035791; Fax: +49 241 82459
E-mail: smoehlhenrich@ukaachen.de